# DEVELOPMENT OF NEW INJECTOR FOR COMPRESSED NATURAL GAS ENGINE AND THE EFFECT ON PERFORMANCE

**SEMIN**

**DOCTOR OF PHILOSOPHY**

**UNIVERSITI MALAYSIA PAHANG**

**UNIVERSITI MALAYSIA PAHANG**

**CENTER FOR GRADUATE STUDIES**

We certify that the thesis entitled “Development of New Injector for Compressed Natural Gas Engine and the Effect on Performance“ is written by Semin. We have examined the final copy of this thesis and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy in Automotive Engineering. We herewith recommend that it be accepted in fulfillment of the requirements for the degree of Doctor of Philosophy specializing in Automotive Engineering.

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**DEVELOPMENT OF NEW INJECTOR FOR COMPRESSED NATURAL GAS ENGINE AND THE EFFECT ON PERFORMANCE**

**SEMIN**

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Doctor of Philosophy in Automotive Engineering

**FACULTY OF MECHANICAL ENGINEERING**
**UNIVERSITI MALAYSIA PAHANG**

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# UNIVERSITI MALAYSIA PAHANG

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# LIST OF SYMBOLS

| | |
|---|---|
| $C_a$ | Area concentration ratio |
| $C_v$ | Velocity coefficient |
| $d$ | Nozzle orifice diameter |
| $D$ | Particle diameter |
| $d_o$ | Jet orifice diameter |
| $k$ | Boltzmann's constant (1.38 x $10^{-23}$J/K), proportionality constant |
| $l$ | Orifice length |
| $MW_{amb}$ | Molecular weight of the ambient fluid |
| $MW_{jet}$ | Molecular weight of the jet fluid |
| $P_a$ | Ambient pressure |
| $P_f$ | Injection pressure |
| $P_t$ | Pressure total |
| $P_{amb}$ | Pressure ambient |
| $r$ | Radial position |
| $r_{1/2}$ | Radial position at which concentration of velocity has decayed to half |
| $Re$ | Reynold number |
| $t$ | thickness |
| $u$ | velocity |
| $u_c$ | Velocity of center of vortex |
| $u_o$ | Velocity at jet origin (sonic) |

| | |
|---|---|
| $u_{cl}$ | Centreline velocity |
| $x$ | Axial position |
| $X$ | Jet fluid mole fraction |
| $X_c$ | Kleinstaein dimensionless jet core length |
| $X_{cl}$ | Jet fluid mole fraction at jet centerline |
| $Y$ | Rorational energy transition branch, jet fluid mass fraction |
| $Y_{cl}$ | Jet fluid mass fraction at jet centerline |
| $Y_o$ | Jet fluid mass fraction at jet origin |
| $z$ | Penetration distance per nozzle orifice |
| $\mu$ | Experimentally fit constant |
| $\mu_a$ | Ambient air viscosity |
| $\Delta P$ | Pressure difference across the orifice length |
| $\theta$ | Cone angle in the measured spray (non-uniform velocity) |
| $\alpha$ | Cone angle |
| $\alpha_a$ | Correction factor for spark ignition engines |
| $\alpha_d$ | Correction factor for compression ignition engines |
| $\rho_a$ | Air density |
| $\rho_{amb}$ | Density of ambient fluid |
| $\rho_f$ | Fuel density |
| $\rho_o$ | Density of jet fluid at orifice |
| $\kappa$ | Kleinstein decay constant for velocity or concentration |
| $\eta$ | Dimensionless radial distance |

## LIST OF ABBREVIATIONS

| | |
|---|---|
| A/F | Air-fuel |
| BBDC | Before bottom death centre |
| BDC | Bottom death centre |
| BMEP | Brake mean effective pressure |
| BSFC | Brake specific fuel consumption |
| BTDC | Before top death centre |
| CA | Cam timing angle |
| CC | Combustion chamber |
| CNC | Computer numerical control |
| CNG | Compressed natural gas |
| COD | Coefficient of discharge |
| CR | Compression ratio |
| DCNGE | Dedicated compressed natural gas engine |
| DD | Degree diffuser |
| DH | Diameter holes |
| DN | Degree nozzle |
| ECU | Electronic control unit |
| EGR | Exhaust gas recirculation |
| H | Holes |
| HAJI | Hydrogen assisted jet ignition |

| | |
|---|---|
| HC | Hydrocarbon |
| HPDI | High pressure direct injection |
| HVAP | Heat vaporization |
| IMEP | Indicated mean effective pressure |
| ISFC | Indicated specific fuel consumption |
| ISO | Interntional standardization organization |
| LHV | Lower heating value |
| MBT | Max best torque |
| NG | Natural gas |
| NGV | Natural gas vehicle |
| OE | Original equipment |
| PIV | Particle image velocimetry |
| PMEP | Pumping mean effective pressure |
| P-V | Pressure-Volume |
| RPM | Radius per minute |
| SI | Spark ignition |
| SIPGE | Spark ignition producer gas engine |
| SPI | Sequential port injection |
| SULEV | Super ultra low emissions vehicle |
| TDC | Top death centre |
| THR | Throttle |
| TVI | Trans valve injection |
| ULEV | Ultra low emission vehicle |

# ABSTRACT

This thesis deals with the experimental and computational assessment of a new injector nozzle for a sequential port injection CNG engine. The objective of this thesis was to develop, analyse and investigate the performance characteristics of a new injector nozzle. The methodology of this study was to convert a diesel engine to a CNG engine with modifications the piston and enhancements the spark ignition and throttle based on computational design using GT-Power and experimental results using an eddy current dynamometer. Next, a simulation of the fuel flow of the new injector nozzle was made using Cosmos FloWok. The final objective was to investigate the performance characteristics of the CNG engine using the new injector nozzle. The investigation focused on engine performance based on variations in engine speed. The engine experiments were conducted according to ISO 3046 for reciprocating internal combustion engine performance. The results showed that the conversion of the diesel engine to a CNG engine reduced engine performance. The simulation of the fuel flow of the new injector nozzle increased the spray distribution, fuel-air mixing and fuel flow velocity. The performance characteristics of the new injector nozzle increased the CNG engine's performance and reduced its fuel consumption compared to the original injector. In conclusion, this study reports that the improvement of a new injector nozzle for a CNG engine significantly increased the engine's performance and fuel consumption.

# ABSTRAK

Tesis ini membentangkan penyelidikan menggunakan percubaan dan berasaskan komputeran bagi penyuntik baru dengan banyak sais lubang untuk penyuntikan melalui paip masuk secara beraturan pada engine gas semulajadi termampatkan dan akibatnya untuk prestasi enjin dan aliran bahan api. Objektif tesis ini ialah membangunkan penyuntik baru dengan banyak sais lubang untuk penyuntikan melalui paip masuk secara beraturan pada enjin gas semulajadi termampatkan dan mengenalpasti akibatnya pada prestasi enjin dan aliran bahan api. Tesis ini berasaskan pengenalpastian menggunakan komputeran dan percubaan. Enjin gas semulajadi termampatkan menggunakan penyuntik melalui paip masuk ini dibangunkan daripada enjin diesel dengan mengubahsuai dan menambah beberapa bahagian-bahagian yang baru. GT-Power perangkat lunak komputeran telahpun digunakan untuk pembangunan model komputeran dan pengenalpastian daripada prestasi enjin berbahan api gas semulajadi termampatkan. Cosmos FloWork perangkat lunak komputeran telahpun digunakan pada semburan, percampuran dan kelajuan aliran bahan api daripada penyuntik baru dengan banyak sais lubang melalui paip masuk secara beraturan pada enjin gas semulajadi termampatkan. Eddy current dynamometer telahpun digunakan pada pengenalpastian prestasi enjin gas semulajadi termampatkan dengan penyuntik melalui paip masuk. Pemodelan komputeran dan percubaan ini dipusatkan pada pengenalpastian prestasi enjin berasaskan pada berbezaan-perbezaan kelajuan enjin. Percubaan pengenalpastian prestasi enjin mengikut pada ISO 3046 untuk prestasi enjin naik-turun pembakaran di dalam. Hasilnya, pengubahsuaian enjin diesel kepada enjin gas semula jadi telahpun nyata menurunkan prestasi enjin. Aliran bahan api daripada penyuntik baru adalah nyata untuk menaikkan semburan bahan api, percampuran bahan api dengan udara dan kelajuan bahan api. Penggunaan penyuntik bahan api baru dengan banyak sais lubang untuk enjin berbahan api gas semulajadi termampatkan menggunakan penyuntik melalui paip masuk telahpun nyata untuk menaikkan prestasi enjin. Hasilnyapun telah nyata menurunkan kadar penggunaan bahan api pada enjin gas semulajadi termampatkan.

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